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A PARTITION OF SMALL GROUP PREDECISION PERFORMANCE INTO INFORMATIONAL AND SOCIAL COMPONENTS

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New theoretical and methodological techniques for partitioning and identifying the sources of performance differences between groups and individuals in hypothesis and act generation tasks are presented in two experiments. Experiment 1 presents a two-component model which separates group performance into informational and social components. The model proposes that the pooling of information in an interacting group (the information —

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component) is mediated by the social factors (e.g., level of arousal, cohesiveness, etc.) which are present in a given situation. Interacting groups were found to be inferior to nominal groups in a hypothesis generation task. Thus, in Experiment 1, the social component was found to have a negative effect on performance. Experiment 2 further partitions the social component into a social information component which accounts for the additional information which becomes available as a result of group interaction and a social, non-informational component which consists of purely social factors. The social information component estimates the synergistic effect of group interaction on information retrieval and problem solving. The social informational component was estimated by including a group of subjects who exchanged ideas (information) via computers but had no social interaction. The "information exchange" group was found to be somewhat superior to a nominal group in an act generation task, and both of these groups were superior to an interacting group. Experiment 2 illustrates that even when the social, non-informational component has a negative effect on the informational component, the social information component may have a positive effect.

A Partition of Small Group Predecision Performance Into Informational and Social Components[1]

The differences in decision making abilities between individuals and face-to-face, interacting groups has been a subject of long-standing interest. The purpose of our study is to present and demonstrate new theoretical and methodological techniques for partitioning and identifying the sources of performance differences between groups and individuals. We illustrate these techniques with the predecision processes of hypothesis and act generation.

Predecision processes are the cognitive processes that precede the selection of a course of action. Hypothesis generation is a predecision process involving the generation of possible explanations (sometimes called "states of the world") to account for the data within a problem context (see Gettys and Fisher. 1979.) Act generation is a predecision process which involves generating the various courses of action which are available to the decision maker.

Previous research examining hypothesis generation by individuals has demonstrated deficiencies in every context examined (Fisher, Gettys, Manning, Mehle, & Baca, in press; Manning, Gettys, Nicewander, Fisher, & Mehle, 1980; Mehle, Gettys, Manning, Baca, & Fisher, 1981; Gettys, Mehle, Baca, Fisher, & Manning. Note 2.) Research on act generation by individuals has yielded similar conclusions (Pitz, Sachs, & Heerbooth, 1980; Gettys, Manning, & Casey. Note 3; Pliske, Gettys, Manning, & Casey. Note 4). In realistic situations, individuals often produce sets of hypotheses or acts which are insufficient, both in terms of quantity and quality, to allow an optimal or nearly optimal choice to be made.

A possible remedy for such deficiencies would be to replace individuals with face-to-face groups or alternatively with nominal groups (Osborn, 1957). Members of a face-to-face group can pool their knowledge and, in addition, the responses of one individual in a face-to-face group may serve as synergistic retrieval cues or prompts which cause others to retrieve additional information. In a nominal group (as defined by Taylor, Berry and Block, 1958), there is no interaction between group members. Instead, the contributions of individuals who worked independently (hereafter referred to as "solo individuals" or "solo subjects") are pooled post hoc.

Do face-to-face or nominal groups significantly outperform solo individuals in hypothesis or act generation tasks? Previous studies which are pertinent to this question involve experimental tasks which share an important characteristic, divergence, with the tasks of interest in the present study. A divergent task is a task in which there is no single "correct" solution. Rather, there are many or an infinite number of solutions which cannot be generated by any straightforward mechanical rule. Most studies have dealt with face-to-face group, nominal group, and individual performance in divergent tasks. These tasks are most frequently referred to as "brainstorming" tasks, although terms such as "creative", "eureka", "idea generation" and "imagination" are also used.

A surprising result of the research involving divergent tasks is that the old adage "two heads are better than one" is not always true. For example, Lorge, Fox, Davitz and Brenner (1958) surveyed a number of studies that contrasted group and individual performance and concluded that groups often do no better than the best individual in the group. Campbell (1968) found that group responses were inferior to those of a single subject. However. other studies of tasks requiring complex judgments (Gustafson, Shukla, Delbecq and Walster, 1973; Hall, Mouton and Blake, 1967; Klugman, 1947) have found groups to be superior to individuals.

With a few exceptions investigators have reported a rather robust result: when combined by some algorithm, the responses of individuals working alone is superior to the responses of groups whose members were permitted to interact freely (Bouchard, 1972; Dunnette. Campbell and Jaastad, 1963; Gordon, 1923; Graham, 1977; Harari and Graham, 1975; Maginn and Harris, 1980; Street, 1974; Stroop, 1932; Taylor et al., 1958; Van de Ven and Delbecq, 1971, 1974; Zajonc, 1962). Yet in some sense the old adage should be true; two heads should contain more information than one. However, this information may not always translate into superior group performance, possibly due to social factors that are operative in a group situation.

The major difficulty with previous research examining group performance in divergent tasks is that there has been no attempt to separate the informational factors from the social factors which are present to varying degrees in face-to-face and nominal groups. That is, there have been no theoretical or methodological techniques to permit the determination of the factors responsible for performance differences between individuals and different types of groups. Therefore, the present investigation presents two alternative models which can be used to isolate these performance differences.

Experiment 1 was our initial attempt to separate empirically the components of group performance. The two component model explored in Experiment 1 may be sufficient to identify the source of performance differences between groups and individuals to a level of detail sufficient for some purposes. Experiment 2 elaborates the model of group performance by isolating an additional component and generalizing the results to another predecision task. The three component model of group performance presented in Experiment 2 may be useful for some theoretical purposes.

A two-component partition of group performance

The effect of pooling information. Suppose that two solo individuals work on a divergent problem solving or decision making task. If the relevant information produced by one solo individual is later combined with that of the other, a nominal group of size two is formed. We would expect this combined store to be superior to that of either solo individual. In this sense, two heads **should** contain more information than one[2].

If there is no overlap or duplication between the two sets of information, two heads should be, on the average, twice as good as one. However, in realistic tasks, there will be some redundancy between two solo individuals' information stores as a result of common knowledge and experience. Thus, the performance of a nominal group of size two, P_N, can be symbolized as in Equation 1. Where I_a and I_b represent the performance of two solo individuals, a and b, and $I_{a \cap b}$ represents the redundancy in performance which results from the pooled information store.

(1) $$I_a + I_b - I_{a \cap b} = I_{a \cup b} = P_N$$

Given the above assumptions, we can conclude that two heads will be better than one, but, due to redundancy, they will not be twice as good as one. Thus,

(2) $$I < P_N < 2I,$$

where I is the average performance of a solo individual and P_N is the actual performance of a nominal group of size two. In an average sense, each time the information produced by a new solo individual is added to the pool, the amount of unique, non-redundant information contributed by a solo individual becomes smaller (cf., Steiner, 1966).

The only factor that distinguishes a nominal group from a solo individual is the pooling of responses according to some algorithm (done post hoc by the experimenter). Since there is no communication between group members, effects due to social interaction cannot be operative in a nominal group.

Effects due to social interaction. A face-to-face group provides the opportunity for social interaction. Social interaction gives rise to several factors which may cause the performance of a face-to-face group to be different from that of a solo individual or a nominal group. Some of these factors are "purely social" factors such as motivation, level of arousal, social comparison processes, tendency to polarize, cohesiveness, interpersonal attraction, social facilitation, dominance, etc. Social interaction may also give rise to "social informational" factors which are often thought to be synergistic in nature. Examples of social informational factors include the combination of partial information from different group members, and the generation of new or improved ideas as a result of the sharing of ideas between group members.

A two-component partition of group performance. The simple version of the proposed model includes two major components which define the performance of a face-to-face group as follows: 1) an information component, which includes the effect of pooling information, and 2) a component due to social interaction, which includes both "purely" social factors and social informational factors. The model proposes that the pooling of information in a face-to-face group is mediated by social interaction, which causes more or less information to be pooled than would occur in the absence of social interaction. This way of partitioning face-to-face group performance is represented in Equation 3.

(3) $$P_{ftf} = P_N + S.$$

where P_{ftf} is the performance of a face-to-face group and S is the effect of social interaction on face-to-face group performance. P_N should be positive (disregarding misinformation), but S may be either positive or negative. In practice, an estimate of the effect of social interaction on face-to-face group performance can be obtained by subtracting nominal group performance from face-to-face group performance.

Past research and the two-component model. The studies cited above which have shown that nominal groups are superior to face-to-face groups are examples in which social interaction has a negative effect on the pooling of information. On the other hand, Cohen, Whitmyre and Funk (1960) found that, in one experimental condition, face-to-face dyads were superior to nominal dyads in a brainstorming task. In terms of our partition of group performance, this is an example in which social interaction caused increased pooling of information. The manipulation that presumably created this increase was the formation of cohesive dyads.

Jablin, Seibold and Sorenson (1977) found no difference between nominal and face-to-face groups in brainstorming performance. In terms of our partition, this finding could be attributed to a negligible effect of social factors on the pooling of information in the face-to-face groups. However. the power of their experiment was too low to permit a definite conclusion.

The two-component model presented above makes explicit some of the ideas that have been more or less implicit in previous group research. We propose that the performance of face-to-face groups will or will not exceed the performance of nominal groups depending on how social interaction affects the pooling of information. This model should help clarify some of the conflicting findings reported in the group performance literature regarding the potential superiority of nominal groups.

In addition to illustrating how the model may be used to partition group performance, Experiment 1 addresses another difficulty with past research on divergent tasks. This difficulty concerns the lack of agreement among researchers on the appropriate dependent measure to use in divergent thinking tasks (cf., Stein, 1975). Much of the early work on divergent thinking used the **quantity** of responses as the primary dependent variable. This reflects the assumption made by brainstorming proponents that the quality or usefulness of a set of responses is linearly related to the quantity of responses. Although counting the number of ideas generated by a subjects sounds quite easy. there is often some ambiguity in identifying the number of different or unique ideas a subject generated. Some researchers (e.g., Dunnette et al., 1963; Taylor et al., 1958) have tried to assess the quality of the ideas generated by having independent raters evaluate the various ideas.

Unfortunately. observed differences in the performance of nominal and face-to-face groups seem to depend to some extent on the performance measure used. For example, Stein (1975) concludes

> . . . when both nominal and real groups use brainstorming the former outperform the latter in number and even quality of ideas. But, when quality is studied as a function of number of ideas then differences wash out. (p. 95)

Experiment 1 avoids the problems inherent in previous measures of divergent thinking performance by using veridical posterior probabilities as a measure of **quality** of responses in a hypothesis generation task. This measure is explained in more detail below.

The hypothesis generation task.

A divergent task, as we have shown, may be partitioned into informational and social components. Hypothesis generation is an example of a divergent task because the object of the task is to generate as many explanations as possible for a given set of data. These explanations should meet a minimum criterion for plausibility; that is, they should be consistent with the data of the problem and be likely enough to be useful as potential explanations for the data.

The hypothesis generation task used in this study is somewhat novel. and for that reason needs some justification and explanation. Subjects were given a course that a student at the University of Oklahoma had taken, and were instructed to list as many plausible majors for this student as possible. It was possible to interrogate the master files of student enrollments to determine the veridical probabilistic relationships between courses and majors. This task allows a more sophisticated qualitative comparison between nominal and face-to-face groups than has been possible using other tasks.

The "majors from classes" task affords three advantages over traditional brainstorming tasks: 1) objective determination of whether two responses are equivalent, 2) objective evaluation of the quality of responses, and 3) a single measure that reflects both the quantity and quality of an individual's responses. The criterion of performance was objective because of the availability of veridical posterior probabilities. Thus, it was possible to objectively compare the quality of responses obtained from nominal and face-to-face groups by adding together the posterior probabilities of each of the plausible hypotheses generated.

Method

Subjects

The subjects were 80 female students enrolled in an introductory psychology course at the University of Oklahoma. Sixteen of the subjects worked individually; the remaining 64 worked in groups of four.

Procedure

The stimuli were eight written problems to which the subjects made written responses. For each problem, subjects were given a brief description of a course offered by the University of Oklahoma and the associated course number. Courses having large enrollments were chosen for use as problems. See Mehle et al. (1981) for further discussion of this paradigm.

The principle manipulation was a comparison of subjects working alone to subjects working in groups of four. In the solo condition, each of 16 subjects was given the set of eight problems. These subjects were instructed not to discuss the problems with each other. In the face-to-face condition, 16 groups of four subjects each were run. The members of each group were instructed to work together to generate hypotheses for each problem. One group member was chosen to make a written list of all responses made by the group. The individuals and groups were given the same problems.

For each problem, subjects or groups were given five minutes to list all majors of an "unknown student" who took the given course. To discourage subjects from making a "memory dump" of all possible majors, we defined a "plausible major" as any major that includes at least two percent of the students who had taken that course. The concept of plausibility is desirable in this context because it prevented subjects from making the s ecious argument that any major is possible and should, therefore, be a valid response. (In fact, not all majors take all courses.) Therefore, subjects were instructed to include a major only if two percent or more of the students who took the course had that major. Subjects were also told that they would not be penalized if they happened to give a response that did not meet this criterion.

Results and Discussion

The dependent measure for this study was the probability that the major of a student who has taken the given course was contained in the set of hypothesis generated by an individual or group. In order to obtain this measure it was it was necessary to calculate the veridical or actual probability of any set of hypotheses. The computer master record of the course work taken by undergraduate students at the University of Oklahoma was analyzed. For these analyses, the "population" was defined as the current student population at the University of Oklahoma. The computer file contained information on the courses taken over the previous four years by students currently enrolled at the university. The probabilistic relationships between classes and majors obtained by analyzing the computer file were regarded as population parameters and were used as veridical probabilities. An analysis of this type was done for each of the classes presented as data to subjects. The task permitted calculation of the veridical probability that the true state of the world would be included in a particular set of majors.

The total hypothesis set probability was calculated, for each of the eight problems, for each solo subject and for each face-to-face group, by adding together the posterior probabilities of each of the plausible hypotheses. The corresponding expression is:

(4) $$P(\text{Correct}) = \sum P(M|C) > .02,$$

where P(Correct) is the probability that the set of hypotheses contains the correct hypothesis and P(M|C) is the probability of a major given a particular class. In accordance with the instructions given to subjects, majors with veridical probabilities of less than .02 for the course being considered were not included.

Equation 4 can also be applied in evaluating the performance of a nominal group. In this case, the hypothesis sets of the individuals who comprise the nominal group are pooled to create a single set of hypotheses. Redundant hypotheses are deleted from this list and the performance of the nominal group is determined by adding the posterior probabilities of the remaining hypotheses according to Equation 4.

's an ex ple, the datum for one problem was: "Sociology 1113. Int. ti to Sociology." One solo individual generated the hypothesis set: Art, Music, Mathematics, Psychology. Sociology. History. Education, Drama and Nursing. The veridical probability that a student who had taken Sociology 1113 had a major that was an element of this set of hypotheses was calculated to be 22.1 percent. Continuing with this example, a face-to-face group of four subjects generated the set: Sociology. Psychology. Social Work, Chemistry, Zoology, Political Science, Nursing, Journalism, Economics, Drama, Education and Engineering. The veridical probability of this set was calculated to be 34.5 percent.

Problem means for the solo individuals, face-to-face, and nominal groups are presented in Table 1. The column entries in the first two columns are means over 16 individuals and 16 groups, respectively. The third column contains the means of the 1,820 possible distinct synthetic groups of size four (all possible combinations of 16 taken four at a time.) This method of calculating nominal group performance requires a considerable amount of computer time. However, it provides a more accurate estimate of nominal group performance using the available data, since error variability due to the particular random assignment of solo subjects to nominal groups is eliminated.

Table 1

Comparison of Individual, Group and Nominal Hypothesis Set Probabilities

	Mean Probability of hypothesis sets (in percents)		
Problem	Solo individuals	Face-to-face groups of four	Nominal groups of four
A	80.3	85.9	89.2
B	30.0	39.6	49.7
C	32.2	44.1	52.7
D	25.1	34.5	50.8
E	27.6	40.9	49.5
F	31.0	42.6	52.6
G	24.9	30.0	50.0
H	16.7	24.2	37.6
Average	33.5	42.7	54.0

Examining the problem means, face-to-face groups were superior to solo individuals for all eight problems. Also, nominal groups were superior to face-to-face groups and to solo individuals on all eight problems. The binomial probability of one condition exceeding another by chance on all eight problems is less than .004 (i.e., $0.5^8 < .004$). Therefore, face-to-face groups were significantly superior to solo subjects and nominal groups were significantly superior to face-to-face groups.

Estimating the model components

The performance partition described in the introduction permits the estimation of social and information components of group performance. The information component estimates the increased information possessed by the group due to the pooling of their information stores. This component is estimated to be 20.5 percent from the data collected in Experiment 1. This was computed by subtracting the average performance of the solo individuals (33.5) from the average performance of nominal groups of size four (54.0).

The social interaction factor was estimated to be -11.3 percent by subtracting the average performance of nominal groups of size four (54.0) from the average performance of face-to-face groups of size four (42.7). In this task, social interaction was found to **impair** performance. That is, actual social (face-to-face) interaction resulted in poorer performance than the post hoc pooling of solo individual performance (i.e., nominal groups). Because face-to-face groups (42.7) were found to be **somewhat** superior to solo individuals (33.5), these data indicate that a group of hypothesis generators (both nominal and face-to-face) is preferable to a single individual. However, the negative social interaction component estimated above indicates that it is preferable to have hypothesis generators work alone and pool their ideas post hoc, rather than have them work in an interacting face-to-face group.

As the estimates given above illustrate, partitioning performance into social and informational components, gives new insights into group research issues. Had we used a task with a smaller informational component, face-face groups may have been inferior to individuals. Had social interaction facilitated performance, the extent of this facilitation would be unknown unless the information component had been estimated. This technique provides researchers with the necessary tool to isolate information and social components, and thus to gain a greater understanding of the data. Furthermore, using a dependent variable that reflects both the quality and quantity of performance leads to a less ambiguous conclusion.

EXPERIMENT 2

Experiment 1 increased the generality of the result that nominal groups are superior to face-to-face groups in divergent tasks by extending it to a hypothesis generation task. It also suggests that this result and those of others were obtained because social interaction actually **impairs** performance **more** than is gained by pooling and sharing information. The paradox of the superiority of nominal groups in predecision tasks raises an interesting question. **Decision makers usually prefer to work in groups, so they must** believe that working in a group is more productive than working alone. Do decision makers prefer to work in groups for social, interpersonal or other reasons (e.g., diffusion of responsibility) unrelated to the decision making performance of the group? Alternatively, do decision makers prefer working in groups because of informational benefits of group participation which enhance the decision making performance of the group?

Previous studies comparing nominal and face-to-face groups have not addressed this question. To our knowledge, no studies of this kind (including Experiment 1 of the present study) have partitioned the two types of effects due to social interaction that were discussed earlier. One of these effects involves purely social factors (e.g., motivation, social facilitation, etc.) and the other involves social informational factors which are often thought to be synergistic in nature. Both types of effects seem intuitively to be crucial determinants of predecision performance.

One particular social informational factor is especially interesting because it is one of the major aspects of group behavior upon which the brainstorming paradigm is meant to capitalize. This phenomenon has, perhaps unfortunately, been labeled "piggybacking" (Day, 1980) and "hitch-hiking" (Stein, 1975); it involves group members use of each other's ideas as aids (i.e., retrieval cues or prompts) in generating additional or improved ideas. Investigators have, for many years, recognized that hearing the ideas of others may facilitate recall of more and better ideas. For example, Osborn (1957) suggested that "the average person can think up twice as many ideas when working with a group than when working alone" (pp. 228-229). However, this phenomenon has yet to be demonstrated experimentally.

Dunnette et al. (1963) tried to optimize brainstorming performance by having subjects work on a brainstorming problem in face-to-face groups and then solo. Using the same assignment of subjects to groups, nominal groups were formed from the sets of solo responses. These nominal groups outperformed other nominal groups made up of individuals who worked on the problem without the benefit of prior group interaction. While this result is quite interesting in terms of improving brainstorming performance, it does not allow unequivocal interpretation of the reason for the improvement. The improvement was not necessarily due to any sort of "piggybacking." Many alternative explanations exist, such as time spent in the task and rehearsal and recall factors.

A method is needed which will allow unequivocal identification of potentially beneficial or detrimental informational effects of group participation over and above those explained by the simple pooling of information or by purely social aspects of group interaction. Therefore, the three-factor partition of group performance presented in the next section isolates an additional social component which estimates the effect of social interaction on memory retrieval and problem solving ability.

A three-factor partition of group performance

The model presented earlier (see Equation 3) separated face-to-face group performance into two components. One component, P_N, is due to pooling of information and the other, S, is due to social interaction. We now wish to factor the social interaction component into two meaningful, independent components by including a social informational factor. The resulting three component partition of face-to-face group performance is represented in Equation 5.

$$(5) \qquad P_{ftf} = P_N + S_{ie} + S_{ni},$$

where P_{ftf} and P_N are defined as in Equation 3. S_{ie} represents the effect on face-to-face group performance of the additional information that becomes accessible (or perhaps inaccessible) due to the exchange of information between members of the group. We will call this the "information exchange" component. S_{ni} represents the effect of purely social, non-informational factors on face-to-face group performance. Both S_{ie} and S_{ni} may be either positive or negative, depending on whether they improve or impair performance.

The magnitude of the information exchange component can be estimated empirically by comparing nominal group performance with the performance of an information exchange group whose members exchange information in the absence of social interaction, P_{ie}. Thus, the information exchange component can be evaluated as in Equation 6.

$$(6) \qquad S_{ie} = P_{ie} - P_N$$

If P_{ie} exceeds P_N, then the information exchange component is facilitory. If P_N exceeds P_{ie}, then the information exchange component is inhibitory.

The magnitude of the purely social, non-informational component can be estimated empirically by comparing face-to-face group performance with information exchange group performance. This component can be evaluated as in Equation 7.

$$(7) \qquad S_{ni} = P_{ftf} - P_{ie}$$

If P_{ftf} exceeds P_{ie}, then the non-informational, social component is facilitory. If P_{ie} exceeds P_{ftf}, then this component is inhibitory.

A technique for estimating the information exchange component

In order to demonstrate the effect of the information exchange component, an experimental method is needed which will allow measurement of the potential informational advantages (or disadvantages) of group interaction without contamination by purely social factors. Two general strategies exist for estimating the information exchange component. One strategy involves using face-to-face groups, but attempting to modify the interaction of group members in order to minimize inhibitory social pressure. The other strategy involves using a group structure which is basically nominal in nature, but which allows for exchange of information between group members.

The brainstorming paradigm described by Osborn (1957) is a good example of the strategy involving face-to-face groups. Osborn attempted to minimize social pressure by prohibiting criticism and giving instructions such as "the more ideas the better, the wilder the ideas the better." While such instructions are undoubtedly a potent manipulation, they would not accomplish our purpose of completely eliminating the social factors associated with face-to-face groups. Dunnette et al. (1963) conclude that:

> In spite of the stimulus of group brainstorming and our specific directive to avoid all criticism, it was apparent that these persons [research scientists and advertising personnel, most of whom were well acquainted with each other] were inhibited simply by the presence of other group members. The central idea underlying brainstorming of placing a moratorium on all criticism is a good one. It appears, however, that group participation still contains certain inhibitory influences which are not easily dissipated. (p. 37)

Although Street (1974) has shown that the mere presence of other group members has an insignificant effect on brainstorming performance, it seems any sort of face-to-face interaction is bound to entail social pressure of some kind.

For the present study we chose to estimate the information exchange component in the absence of face-to-face interaction. We developed a technique in which subjects worked on an act generation problem in physical isolation from other subjects and were led to believe they were being aided by a computer when, in fact, they were exchanging ideas with another subject. The difference in performance between groups whose members exchanged acts (which we call the information exchange condition) and traditional nominal groups provides an estimate of the information exchange component (see Equation 6). If this component is found to be positive, it can be concluded that there is a benefit of group interaction which is due neither to the information available to group members independently (in the absence of interaction), nor to purely social effects of group interaction.

If the information exchange component is found to be negative, it can be concluded that there is a detrimental effect of group interaction which can be explained neither by group members' independent lack of knowledge nor by purely social factors. A negative information exchange component could, for example, be due to subjects causing each other to "get in a rut" and pursue a single train of thought to the exclusion of other good ideas. Alternatively, the "getting in a rut" phenomenon could be created by purely social factors. In this case, the phenomenon would occur in face-to-face groups, but not in information exchange groups. Therefore, referring to Equation 5, the phenomenon would decrease S_{ftf}, but have no effect on S_{ie}.

In terms of our extended partition of group performance (Equation 6) the previously-mentioned finding of Cohen et al. (1960) that cohesive face-face groups were superior to nominal groups may be attributable to either (or both) the information exchange component or the social, non-informational component. The only conclusion that can be drawn from their data is that the sum of these components is positive and, therefore, there is an overall facilitory effect of group interaction. It cannot be concluded that both social components were positive.

Experiment 2 illustrates how our extended partition of group performance can be used to identify the source(s) of performance differences between different kinds groups. Nominal, face-to-face, and information exchange groups were compared in terms of quality of sets of responses produced. A new experimental technique is presented which allows exchange of information between group members without contamination by the purely social factors and social demand characteristics that are generally active in face-to-face groups.

Experiment 2 generalizes the partitioning technique to a different predecision task, act generation. The hypothesis generation task used in Experiment 1 permitted the use of veridical probabilities as a measure of performance. However, for many real world decision problems veridical probabilities are not available. Experiment 2 also illustrates how the partitioning technique can be used with another dependent measure. Subjects were given a realistic decision problem and were asked to generate actions which could be taken to solve the problem. Their performance was scored in terms of quality, as well as quantity, of the actions they generated.

Method

Subjects

The subjects were 139 male and female introductory psychology students from the University of Oklahoma who participated in the experiment for course credit. Subjects with typing skills were solicited. Those who failed a 20 word per minute typing test were not permitted to participate in the experiment. Subjects were given three chances to pass the test. Data from three subjects in the solo condition, three pairs of subjects in the information exchange condition and five pairs of subjects in the face-to-face condition were not analyzed because their post-experimental questionnaires indicated they ran out of time before completing the experiment. The data reported below are based on 40 subjects per condition.

Problem

The decision problem we used was called the Parking problem. This problem asked subjects to imagine themselves to be members of a student committee which is supposed to come up with alternative solutions to the parking problem at the University of Oklahoma. Previous research (Gettys et al., Note 3) has indicated that college subjects find this act generation task realistic and meaningful. It is also an attractive problem, because it is a specific example of a more general type of problem faced by many decision-makers. That is, the Parking problem is essentially a shortage problem in which the decision-maker is faced with a shortage of a valuable commodity (i.e., parking places.)

The use of a covariate to reduce error variance

We included a pretest as a covariate in the present experiment in anticipation of large individual differences in act generation performance as have been found by Gettys et al. (Note 3) and Pliske et al. (Note 4). Manning et al. (1980) found that the Alternate Uses creativity test developed by Christensen, Guilford, Merrifield and Wilson (1960) and discussed by Guilford, Christensen, Merrifield and Wilson (1978) is a good predictor of hypothesis generation performance. Since hypothesis and act generation are similar cognitive tasks, the Alternate Uses test may also be predictive of act generation performance.

Our version of the Alternate Uses test is a paper and pencil test which includes 10 items. For each item, the subject is to list all possible uses for an object other than the use commonly associated with the object. For example a coat hanger may be used unlock a car or roast food over a fire; a brick may be used as a doorstop or to crack walnuts, etc.

Procedure

The Alternate Uses test was administered during the first 15 minutes of the session. Subjects were then randomly assigned to conditions. For the remainder of the experiment, subjects were seated in front of a CRT terminal which was controlled by a computer. They interacted with the computer by reading textual material displayed on the CRT screen and by typing in their responses via the keyboard.

Experimental conditions

The three experimental conditions will be referred to as solo, information exchange, and face-to-face. In the solo condition, a single subject was seated before the terminal and no other subjects were in the room. In the face-to-face condition, two subjects were seated before the terminal. Prior to the experimental session, one of these subjects was randomly designated as the typist. (However, if this subject failed the typing test, the other subject was allowed to attempt it.)

In the information exchange condition, two subjects participated simultaneously in different rooms using different computers. Subjects were unaware of each other's presence. As in the solo condition, a single subject was seated in front of the CRT. In the information exchange condition, the lower half of the CRT screen was dedicated to the act the subject was entering and the upper half to acts "from the computer." Acts typed in by one subject were automatically sent to the other subject.

Instructions

Subjects were instructed to generate all possible acts that might solve the problem. However, they were cautioned not to suggest "frivolous or counterproductive" acts or minor variations of a single act. They were told that the experiment would consist of only two problems, a practice problem and an experimental problem and that there would be no time limit on the experimental problem. In addition to reading these and related instructions on the screen, subjects were given a paper copy of the instructions in case they wished to refer back to it later in the experiment. In the face-to-face condition, subjects were told that they would be working together as a team and that the performance of their team was the variable of interest to the experimenter.

Information exchange subjects were presented with the following additional instructions (both on the screen and on paper):

> The computer has been programmed to attempt to help you come up with actions which could be taken. Stored in the computer's electronic memory are a large number of possible actions for the problems you will be working on. These actions were suggested by subjects in a previous experiment. You will not be required to read through all of

the actions that the subjects suggested, as that might take several hours. Instead, the computer program will do this for you. Each time you finish typing in an action that you have thought of, the program will attempt to interpret the basic ideas involved in your suggestion. Then, while you are thinking of more actions and typing them in, the program will automatically search through the computer's memory for actions that are related to yours. Whenever such an action is found, it will be displayed on the screen and you will hear a "beep." Also, whenever this happens, the action will be added to your list of actions (and to your score in the experiment) just as if you had thought of it yourself.

The computer program is still in the developmental stages and has only a limited ability to interpret actions that you suggest. Therefore, don't be alarmed if actions appear on the screen which are not closely related to your suggestions. Also, some of the actions that appear may be quite bad. No attempt has been made to "weed out" ridiculous or counterproductive actions from the computer's memory. However, such actions will not affect your score.

When an action from the computer appears on the screen, be sure to read it right away. Otherwise it may be replaced by something new before you have finished reading it.

The practice problem

Subjects in all groups were given a practice problem in which they were asked to think of acts which could be taken if one ran out of gas on the highway and had no money. They entered one act at a time. Each time subjects indicated that an act was complete, they were required to explain how the act might solve the problem. This was done to aid the experimenters in determining what subjects hoped to accomplish with the acts they suggested. When the explanation was finished, the act and explanation disappeared from the screen and subjects were given the opportunity to enter another act.

For the solo and face-to-face conditions' practice problems, subjects were required to enter and explain three acts. When the third act and explanation was complete the computer displayed three exemplar acts generated by a creative subject to encourage them to think of as many acts as possible.

For the information exchange condition, the computers were interconnected and programmed such that until both subjects had entered a minimum of three acts in response to the practice problem, both subjects were required to continue entering additional acts. This was necessary to insure that both subjects started the experimental problem at the same time. Contrary to the instructions, the computers had no ability to interpret the substance of subjects' acts. After subjects completed their first act (and explanation) one of the three exemplar acts was displayed on the screen. The other two exemplar acts were displayed at approximately two minute intervals while the subject was entering other acts. Only one exemplar act was visible at a time. When an act from the computer appeared on the screen, the keyboard was disabled for one or two seconds, after which the subject could continue typing.

In all conditions, subjects were not told how many acts to enter for the practice problem. They were told that the computer would proceed automatically at the proper time. The experimenter helped them during the practice problem to insure that they understood the instructions and were able to interact with the computer without difficulty.

The experimental problem

After subjects were shown the exemplar acts, the text describing the parking problem on the University of Oklahoma's campus was presented on the screen. The text of the problem is given in Gettys et al. (Note 3). Subjects were also given a paper copy of this text for later reference. They were reminded to enter all reasonable acts which might have even a remote possibility of solving the problem. For the experimental problem, any number of acts could be entered and no example acts were given to solo or face-face subjects. Otherwise, the instructions for each condition were the same as for the practice problem and subjects interacted with the computer in the same way.

Each time an information exchange subject finished entering an act for the experimental problem, it was transmitted immediately to the other computer and it appeared on the upper half of the other subject's screen. In this way, the two subjects exchanged acts throughout the experimental session, without being aware that they were doing so.

All subjects were verbally instructed to inform the experimenter "if you completely run out of reasonable ideas." When they informed the experimenter that they had indeed run out of ideas, they were asked to fill out a post-experimental questionnaire. They were not told about the questionnaire prior to this time. The questionnaire included open-ended, multiple choice, and Likert scale items concerning strategies subjects used to come up with acts, how many more acts there might be, possible reasons for terminating the experiment (e.g., did you run out of time? Did you find yourself thinking of more and more bad ideas?) and whether the computer (information exchange condition) or their partner (face-to-face condition) was a help or a hindrance. All subjects worked independently on the questionnaire.

Results and Discussion

Number of acts generated

The Alternate Uses test was significantly correlated with each of the dependent variables examined. Correlations ranged from .26 to .37. Therefore, the Alternate Uses scores were included as a covariate in all analyses of variance and are reflected in all F statistics reported below.

In the face-to-face condition, a single set of act generation data was collected for each pair of subjects. The average number of acts generated by face-to-face pairs was 11.3. For the solo and information exchange conditions, a set of data was collected from each individual. However, the unit of primary interest for all conditions is the combined performance of two subjects. The mean number of acts generated by information exchange pairs was 27. For the solo condition, nominal groups (alternatively called "solo pairs" or "nominal pairs") were formed by randomly pairing subjects. The mean number of acts generated by nominal groups was 19.1. There was a significant difference in mean number of acts generated, $F(2,56)=16.81, MS_e=65.7$, $p<.0001$. Individual comparisons show that all three of these means are significantly different from each other ($p<.05$).

The mean number of acts generated by the 40 solo subjects (not pairs) was 9.6. Since this mean was lower than all three means given above for pairs, it is of interest to compare the number of acts generated by solo subjects with that for the lowest of the others, face-to-face pairs. Twenty solo subjects were selected at random for comparison with face-to-face pairs. The mean number of acts generated by these twenty subjects was 9.9. This mean was not significantly different from the mean number of acts generated by face-to-face pairs. Thus, two people working as a face-to-face team did not generate significantly more acts than a single person working alone.

Classification of acts

Many of the acts generated by the subjects were conceptually quite similar. For example, one subject might suggest that the University build a parking lot next to the library, whereas another subject might suggest building a parking lot next to the student union. We classified the 1148 acts generated by the subjects into a 40 category hierarchical decision tree to determine how many **unique** acts subjects had generated. This tree was developed by Pliske, et al. (Note 4) (where it is presented in its entirety) in order to capture the major ideas expressed in subjects' acts for solving the Parking problem. The two acts described above would both be classified into a category labeled "Build new parking on University land."

The tree was intended to include the broadest possible range of reasonable actions for solving the problem. This was done because of the emphasis that brainstorming advocates place on generating a wide variety of different ideas. It is assumed that refining or "tweaking" (Edwards, Note 5) in order to arrive at the best possible variation of a general solution would not be done until all of the relevant ideas have been considered.

Two raters independently classified the acts into the tree. The raters were not told which condition the acts were from. The percentage of agreement for the two raters was 92 percent. The acts that the raters disagreed on were discussed in conjunction with several of the authors until everyone agreed on an appropriate classification.

Results based on number of unique acts

About 4 percent of the acts had to be eliminated because they were either blatantly counterproductive (e.g. "nuke the university") or because they were incoherent and impossible to interpret. Forty reasonable, unique acts were possible under our classification system. After the "bad" acts were eliminated, solo pairs generated an average of 12.25 unique, reasonable acts. Information exchange pairs generated an average of 14.1 and face-to-face pairs generated an average of 8.3 unique, reasonable acts. Analysis of variance on these three means was significant, $F(2,56)=16.69, MS_e=9.29$, $p<.0001$. Individual comparisons revealed that all three pairwise combinations of means were significantly different from each other ($p<.05$). The mean number of unique, reasonable acts generated by the 20 randomly chosen solo subjects (not pairs) was 7.3. This mean was not significantly different from that for face-to-face pairs.

Quantity of unique responses has been the traditional dependent variable in brainstorming research. Our conclusions about performance based only on the **quantity** of unique responses can be summarized as follows:

face-to-face pairs < solo pairs < information exchange pairs (or solo subjects)

A single person working alone produces as many unique, reasonable solutions as two people working together face-to-face. However, two heads are better than one, in an average sense, because solo pairs perform better than individual solo subjects. Furthermore, there is a benefit of the exchange of ideas between subjects, since information exchange pairs performed better than would be predicted from the simple pooling of the responses produced by an equal number of individuals working solo.

Utility estimation procedure

In addition to developing the act classification tree, Pliske, et al. (Note 4) obtained utility estimates for each of the 40 categories included in the tree. The utility estimates were global estimates of the quality of actions. They took into account the cost of implementing an action and the likelihoods of the various outcomes which may result from the action. Pliske, et al. elicited utility estimates from five "experts" (university administrators) who were knowledgeable about the parking problem on campus. The utility estimation procedure involved four steps beginning with categorizing 40 generic actions, which corresponded to the 40 categories in the act classification tree, into five categories according to usefulness and ending when all acts had been rated on a 0 to 100 point utility scale. The correlations between the experts' utility ratings were fairly high. A utility value was assigned to each of the 40 categories by finding the median of the experts' ratings for that generic act.

Results based on quality of acts

Using our classification system and associated utility values, it was possible to characterize the quality of the acts suggested by summing the utilities of the unique acts. (The "bad" acts were assigned the value 0.) The mean cumulative utility for solo pairs was 637, for information exchange pairs 681, and for face-to-face pairs 401. An analysis of variance on these three means was significant, $F(2,56)=19.61, MS_e=19659.69, p<.0001$. Individual comparisons showed that the face-to-face condition was inferior to both of the other conditions ($p<.05$), but solo pairs and information exchange pairs did not differ significantly. The mean cumulative utility for the 20 randomly chosen solo subjects (not pairs) was 359. This mean was not significantly different from that for the face-to-face condition.

Therefore, in terms of quality of unique acts, both a nominal group (solo pairs) and an information exchange group were found to be superior to a face-to-face group. However, there was not a significant improvement in the quality of ideas generated by the information exchange pairs as compared to the solo pairs. Furthermore, a face-to-face group of two people was not found to be, on the average, any better than a single person working alone.

A similar result is obtained when the quality of the best act that was generated is examined. This measure is of particular interest in tasks that involve mutually exclusive acts, such that only one of the possible acts can be implemented. For the Parking problem, some of the acts preclude each other and some do not. However. the utility of the best act generated by a subject or group is of interest since it is an act that would surely be implemented.

The average utility of the highest utility act generated by solo pairs was 90.6, for information exchange pairs 89.2, and for face-to-face pairs 81.15. An analysis of variance on these means was significant, $F(2,56)=8.77$, $MS_e=895.0$, $p<.001$. Individual comparisons showed that the face-to-face condition was inferior to both of the other conditions ($p<.05$), but the other two conditions did not differ significantly. The average utility of the highest utility act generated by the 20 randomly chosen solo subjects (not pairs) was 85.05. This mean was not significantly different from that for the face-to-face condition.

The results presented above indicate that observed differences between nominal, information exchange, and face-to-face groups depend to some extent on the performance measure used. It appears that the preferred dependent measure would be one which reflected both the quantity and quality of a subject's performance. The cumulative utility measure presented above encompasses both aspects of a subject's performance because it is affected by both the number and quality of the acts generated by a subject. Therefore, we illustrate the three component model presented in the introduction to Experiment 2 using the cumulative utility of the acts generated by the subjects.

Estimating the model components.

We now have all of the information necessary to estimate the magnitude of the information exchange component and the purely social, non-informational component of face-to-face group performance. From Equation 6, the information exchange component, S_{ie} is equal to information exchange group performance minus nominal group performance. Thus,

$$S_{ie} = 681 - 637 = 44$$

The information exchange component results in an increase in performance of 44 utiles. This represents a 6.5 percent increase in performance.

From Equation 5. the magnitude of the "purely" social, non-informational component, S_{ni}, is the difference between face-to-face group performance and information exchange group performance. Thus,

$$S_{ni} = P_{ftf} - P_{ie} = 401 - 681 = -280$$

The purely social component results in a decrement in face-to-face group performance of 280 utiles. This represents a 41 percent decrement in performance due to purely social, non-informational factors.

It is also possible to estimate the total effect of social interaction, S (see Equation 3). This effect is equal to the difference between face-face group performance and nominal group performance. (Alternatively, it is the sum of S_{ie} and S_{ni}.) Thus,

$$S = P_{ftf} - P_N = 401 - 637 = -236$$

social interaction results in a decrement in face-to-face group performance of 236 utiles. This represents a 37 percent decrement in performance.

It can be seen that the overall effect of social interaction is actually a combination of two factors. When the information exchange component was not partitioned out of face-to-face group performance, social interaction appeared to have a smaller inhibitory effect on performance. In fact, the effect of purely social factors on face-to-face group performance is so large that it more than negates the informational benefits that also result from social interaction.

The redundancy of information contributed by individuals

As discussed earlier, if there is no overlap between the information held by two solo individuals regarding a task, then a nominal group formed from the responses of the two individuals should, on the average, perform twice as well as the average solo individual. Any redundancy between the two individuals' information stores would result in nominal group performance less than twice as good as the average solo individual.

A measure of the redundancy of information contained by solo individuals in the present experiment can be obtained by comparing the performance of a nominal group of size two with two times the performance of a solo individual. In terms of cumulative utility, the average performance of nominal groups was 637 utiles while twice the average performance of solo subjects was 718. Therefore, considering the effect of information on act generation performance, on the average, about 40.5 utiles or 11 percent of the information possessed by one nominal group member was redundant with that of the other member.

Differences between information exchange and nominal groups

Information exchange pairs generated an average of 41 percent more unclassified acts than nominal pairs. However, the average number of unique acts (the number of acts after classification into the 40 category tree) for information exchange pairs was only 15 percent greater than that for nominal pairs. This result indicates that information exchange pairs generated multiple acts in the same category more frequently than did nominal pairs. A question arises as to the nature of these variations of the generic acts. Possibly, information exchange subjects generated minor improvements on each other's (or their own) acts. In fact, this is what one might expect a subject to do if the information "exchanged" helped the subjects to retrieve additional information with which they could create new solutions to the problem. For this "tweaking" behavior to be most productive, they should have generated variations of the best acts, since these are the ones most likely to be implemented.

The dependent measures of quality which we have considered thus far do not address this question. As discussed above, information exchange pairs performed only 6.9 percent better than the nominal pairs in terms of cumulative utility. Also, nominal pairs performed slightly better, although not significantly. in terms of the average utility of the highest utility act generated. These measures are affected only by whether a category was generated. They are not sensitive to multiple acts classified in the same category.

A new dependent measure of quality, the average utility per act, was computed for each subject. This measure was based on the utility of all the acts generated (i.e., unclassified acts) without regard to uniqueness. Although there were some redundant acts in all conditions, if information exchange pairs had a greater tendency to generate redundant acts of high utility, their average utility scores (when those scores are based on the utility of all acts generated) should be higher than the average utility scores for the other conditions. However, the data from the present study indicate that these means were nearly the same for all conditions and for solo subjects. The average utility per act for the information exchange pairs was 46.1; the average utility per act for the solo pairs was 46.0; the average utility per act for the-face-to face pairs was 46.0; and for the 20 randomly chosen solo individuals the average utility per act was 46.5.

We can conclude from this analysis that although information exchange subjects generated more variations of each of the 40 generic acts which comprised the 40 category decision tree used to classify subjects' responses, these variations were not restricted to the high-utility generic acts. That is, the average utility or quality of the acts generated by subjects in the information exchange condition did not differ from the average utility of the acts generated by the other conditions. The information exchange component of group performance in the act generation task used in the present experiment appears to primarily affect the quantity, but not the quality, of the acts produced.

One possible explanation for this finding is related to the fact that subjects were instructed to generate all possible, reasonable acts regardless of utility. They may indeed have given little consideration to utility in deciding which ideas to pursue in attempting to generate additional acts. The information exchange component would probably be larger in tasks that are less divergent in nature. In such tasks, the "piggybacking" phenomenon of improving on each others ideas might be more more facilitory.

Differences between nominal and face-to-face groups

The performance of face-to-face pairs was found to be inferior to both the solo pairs and the information exchange pairs on all of the dependent measures examined in Experiment 2. This is consistent with many previous studies which compared nominal and real group performance on divergent thinking tasks (cf., Stein, 1975). The face-to-face pairs in Experiment 2 performed no better than a solo individual. This result is somewhat surprising given the increased amount of information which should become available due to the informational and the information exchange components of group performance. Why does the social, non-informational component have such a large, negative effect on act generation performance?

The present study was not designed to explain **why** the social. noninformational component often has a negative effect on group performance. However, data collected in post-experimental questionnaires rule out several potential explanations. When two people work in a face-to-face group, they might tend to evaluate the actions which come to mind before verbalizing these actions to the other group member. Subjects might be more critical of their own act generation behavior when they are placed in a social situation. Subjects in the present study were asked to indicate on a 10-point scale how often they thought of actions but then rejected them as being implausible or unrealistic solutions. The 0 point on the scale was labeled "never" and the 10 point was labeled "always." The mean response for all three conditions was 3.0. This does not support the hypothesis that subjects in the face-to-face condition are more likely to evaluate and reject the actions they think of than subjects in the other conditions.

Subjects were also asked to give us their opinions on several statements describing the experiment. These included statements like the following: "This experiment was challenging", "This experiment was fun," etc. Subjects responded on a 10-point scale where the 0 point was labeled "disagree strongly" and the 10 point was labeled "agree strongly." The only statistical difference of interest was found for a statement given to subjects in the information exchange and face-to-face conditions which stated "The computer [or my partner] helped me think of new ideas." The mean response for this statement from subjects in the information exchange condition was 6.3 and the mean response from subjects in the face-to-face condition was 7.7, $F(1,78)=7.64$, $MS_e=5.3$, $p<.01$. This result suggests that although subjects' act generation performance in face-to-face pairs was inferior to information exchange pairs, subjects in the face-to-face condition rated their partner as being more helpful than subjects in the information exchange condition rated the computer. This result seems to reflect the common assumption made by people that working with others in a face-to-face, interacting group will improve their performance.

General Discussion

In Experiment 1 a two-component model was used to estimate the magnitude of the informational and social components of face-to-face group performance in a hypothesis generation task. Four heads were found to be superior to one in terms of quality performance. However, a large difference was found depending on whether the four people worked together or separately. Social interaction resulted in considerable impairment of hypothesis generation performance.

In Experiment 2, a three-component model was used to estimate the magnitude of the informational, information exchange and purely social components of face-to-face group performance in an act generation task. Two heads were found to be better than one only when there was no social interaction between the two people. Thus, the overall effect of social interaction was negative. However, separation of the effect of social interaction into information exchange and purely social components revealed a small performance benefit produced by group interaction. This benefit was due to the exchange of information between group members. The information exchange effect has been impossible to assess in other studies, because exchange of information between group members is generally confounded with the accompanying social factors which tend to have a powerful deleterious effect on group performance.

The three-component model of face-to-face group performance allows the experimenter to identify more precisely the source(s) of performance differences between various types of groups in divergent tasks. However, a drawback of the three-component model as opposed to the two-component model is that 50 percent more subjects are needed. The two-component model may suffice in many situations.

We see possibilities for elaborating the three-component model in order to isolate additional factors which affect group performance. By systematically varying factors thought to affect group interaction, the researcher should be able to discover which component of the model each factor affects. The components could then be further partitioned to represent the influence of the new factors. In this way, it should be possible to extend the model to address a variety of theoretical questions by elaborating the partition appropriately. For example, instructions designed to modify the interaction of group members could be employed to assess the effect of task-irrelevant behavior on each of the three components of performance. It may be possible to devise similar manipulations to examine almost any aspect of group behavior that is of theoretical interest.

Footnotes

[1]This project was supported by ONR Contract N00014-80-C-0639. Experiment 1 was previously reported in more detail in Casey, Mehle, & Gettys (Note 1). We illustrate the two-component version of the model presented in the present investigation with data originally presented in Casey, et al. We would like to thank Richard Reardon for comments made on an earlier draft of this paper. We would also like to thank Jason Beckstead, Pamela Casey, Carol Manning. and Peter Engelmann for their help with various stages of this project.

[2]It is theoretically possible for the sum of the two solo individual's information stores to be less than that of the most knowledgeable solo individual if one or both solo individuals possess misinformation. It is also possible for the information possessed by one solo individual to be a proper subset of the information possessed by another. We will neglect these interesting, but somewhat pathological possibilities for the present (cf. Casey. Mehle & Gettys, Note 1).

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